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# Brillouin sensing for perimetric detection: the *SMARTFENCE* project

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## ABSTRACT

Security is a rising market, and solutions based on distributed sensing provide answers adapted to requests of citizens and industrials. We developed the *SMARTFENCE* concept, to provide an innovative solution for enhanced perimeter security of critical infrastructures. It includes a new kind of optical cable deployed on fences, a Brillouin instrumentation, and a dedicated signal processing. Several 20 m-long fences were equipped with such sensing cable and tested by commandos, then intrusion signals were used to develop the signal processing. Field trials resulted in a very sensitive solution, thanks to an innovative deployment procedure of optical cables on fences. The project ends with a long term demonstration: an electrical substation, 670 m perimeter, has been equipped with the fiber sensing cable, on two fence levels. This validation provides an important experience feedback and the monitoring system validation.

**Keywords:** Perimetric detection, security, fence, Optical Fiber Sensor, cable, extrusion, Brillouin scattering, distributed sensing.

## 1. INTRODUCTION

Security demand increased during last decade due to high level of instability all over the world, as tensions, arising from terrorism, spying or from criminal actions may induce serious consequences to critical infrastructures. Today, the Homeland Security business is shared into 54 % owned by the US, 20 % by Europe and 26 % by the rest of the world. In the field of civil security, new technologies show a high growth rate to fight most effectively against risks and threats. In the past, several developments have been done, some of them based on optical cables buried into the ground (vibration sensing) [1], or on OTDR and coherent interferences [2]. These last years, several projects dealing with intrusion detection, and based on OFS have also been reported. With long range possibility of fiber sensing, new approaches have been considered as those dealing with distributed sensing [3]. We can mention, a distributed intrusion detection solution based on the combination of  $\phi$ -OTDR and P-OTDR [4], and another one based on a phase-sensitive reflectometer and a Raman amplifier for sensing optical cables made of fiber reinforced plastic, for long-distance (~ 62 km) intrusion monitoring [5].

In this paper, we present the *SMARTFENCE* project which aim consists to increase the security of critical sites by introducing a new approach based on Brillouin (BOTDA) sensing and a new cable design, for perimeter monitoring. Concerning the overall security of a site, we must consider various threats linked to the kind of intruder (casual thief, gang, agent of a foreign country, terrorist...). In some sensitive areas, security must be high level

and therefore difficult to overpass when the intruder is in its coverage zone. SMARTFENCE's targeted applications concern high security level areas with a strategic activity or with no people on place. It includes Nuclear Power Plants, industrial facilities as chemical plants, military bases, embassies, telecom centers, railway lines, complex oil & gas facilities, fireworks sites, fleets, ports...

## 2. SENSING PRINCIPLE

The now well known Reflectometry technique used in Brillouin instrumentations is the optical equivalent of Radar. While light pulses are injected into the fiber, few photons are backscattered from the silica fiber core. This detected backscattered intensity is recorded with respect to time delay converted into distance. Backscattered spectrum is made of several lines: one central at the excitation wavelength (the elastic Rayleigh scattering), and four others which have undergone a shift by inelastic Raman and Brillouin scattering effects. (Fig. 1).

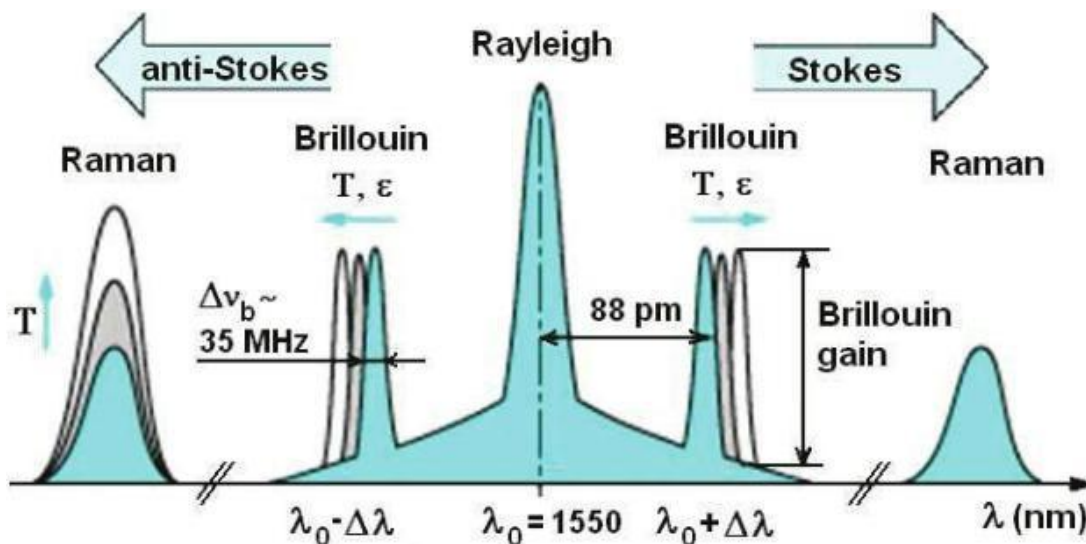


Figure 1. Spectrum of backscattering in silica optical fibers.

The Brillouin phenomenon is the result of the interaction of the traveling light waves and acoustic phonons in the fiber core. Such mechanism generates two frequencies symmetrically shifted with respect to the excitation lines, called Stokes and anti-Stokes lines. This spectral shift  $\Delta\lambda \sim 100$  pm ( $\Delta\nu \sim 12$  GHz) depends on temperatures and strains at any location of the fiber under test. The accurate determination of this frequency shift vs time provides strain and temperature spatial profiles along the fiber. Main performances of the selected Brillouin analyzer are as follows: 1 m spatial resolution, > 10 km range,  $\pm 1.2$  MHz frequency resolution at  $3\sigma$  ( $\pm 25$   $\mu\text{m/m}$  strain resolution), and 3 s response time. The analyzer is connected to the sensing cable deployed on the fence to detect and localize any intrusion or intrusion attempt. Designed and attached in an innovative way, the sensitive cable detects the strain profile all along the fence, and sends an alarm when strain level correspond to an "event" with a 1 m spatial resolution (smaller than a fence panel).

## 3. SMARTFENCE SENSITIVE OPTICAL CABLE

A simple, easy to handle, and strain-sensitive single-fiber solution has been developed to be cost effective, in terms of manufacturing cost as well as in terms of deployment on fence (manpower). The innovating way to install cable on fences, increasing the detection sensitivity is protected by a CEA patent [6]. The cable constitution is depicted on Fig. 2.

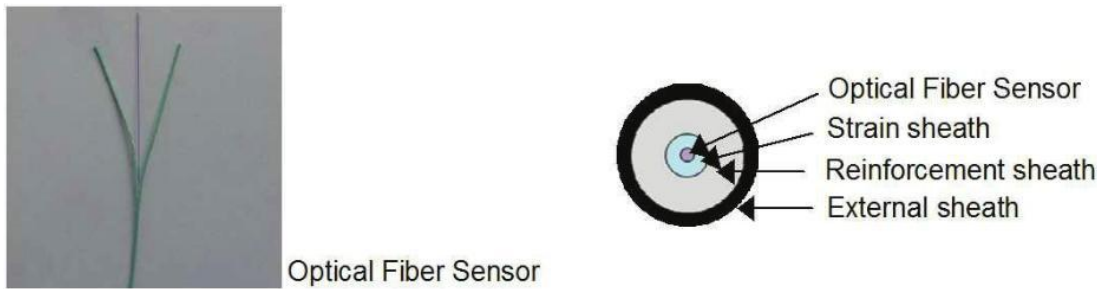


Figure 2. Sensible element of optical cable and Single fiber cable (credit ACOME).

This cable has been developed and realized by ACOME on an industrial extrusion line. This process produces elements of constant straight section. The material shaping is obtained thanks to extruders which transform the granules-based raw products into a plastic state material, then push it into the extrusion crosshead, and inject it through dies around one or several optical fibers passing through the crosshead. The external shape and dimensions of the optical sensing cable are obtained thanks to dedicated female and core dies inserted into the extrusion head. In this project, the optical fiber (250  $\mu\text{m}$  diameter) is covered with 3 peripheral coatings in only one operation. For that purpose, three extruders are associated which converge on a dedicated distribution block. The optical fiber penetrates into this block and the material layers are extruded in a concentric way around the fiber. Finally, the cable passes through a cooling tunnel and is coiled on a drum at the far end of the manufacturing line. So, the optical fiber sensing cable is manufactured using a multi-layer industrial extrusion process, improved during the project, to reduce manufacturing cost. This multi-layer extrusion process is now accomplished in an optimized process, leading to a cost-effective solution easy-to-deploy on existing or new fences

#### 4. SIGNAL PROCESSING AND SUPERVISION SOFTWARE

An heuristic approach based on prior analysis of signals recorded during intrusion testing as well as on calibrations, has been chosen in case of flexible barriers. It includes a specific processing to compensate for the temperature influence (sun, clouds...) by using a sliding Brillouin profile as reference, plus a smoothing procedure and a convolution, before a threshold be applied. Moreover, the software checks if events are simultaneously detected on both levels of the barrier. From such double-detections, and a decision table summing three successive measurements, we obtain a satisfactory detection signal to trigger an alarm wisely, with few false alarms. The acquisition and signal processing software have been developed with Labview®. A part of it is implemented in a local computer connected by Ethernet to the Brillouin system, and to the Security Center by Internet. During development phase, this operational software was mirrored by a simulator software at CEA lab in order to process the data stored on SSD disks with a fast scrolling data (accelerating by a factor of 160) to test signal processing solutions.

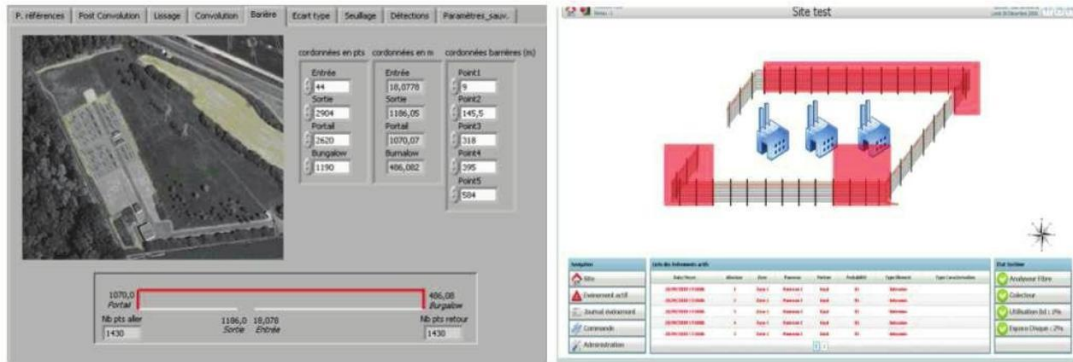


Figure 3. A screen view of the detection software (CEA) and the overview of the control interface (credit SITES).

The Full Web supervision software developed by SITES, including an intuitive User-friendly Interface (UI) and an event database, has been checked on field in order to implement and adjust the full measurement chain. Both the signal processing and the supervision software ensures functionalities as follows: Brillouin system control, recovery of sensing data, data storing in the database, data processing to detect the occurrence of any event while lowering the false alarm rate, Comparison of results with previously acquired references to improve the quality of detection, Transmission of events to the system interface and transfer to the supervisor, and Reception & command interpretation from the UI, *i.e.* a full Web application for viewing the site status. Several remote operators may simultaneously access to data.

## 5. FIELD INSTALLATION AND FUNCTIONAL TESTS

The fiber cable must be fixed on the fence in order to enhance the sensitivity: attached on any fence post and stretched between them with a specific spacer (Fig. 4). First of all, sensing cables were installed on 2 sections of 10 m fence (stiff & flexible) at the experimental field provided by the SPACI, a CEA Department, well-known for its know-how in security systems characterization. Two fence levels were instrumented, at 1/3 and 2/3 of the fence height, enabling the detection and distinction between events, to avoid false alarms. Several intrusion tests have been performed with French army commandos and the best sensing cable design validated.



Figure 4. Cable deployment and SMARTFENCE system, when commandos climb over the fence (credit CEA).

The pilot site chosen for long term validation and qualification is the fence perimeter of an electrical substation from the Réseau de Transport d'Electricité de France (RTE, the French Electricity Network). The overall fence length is 670 m, and the sensing cable, forming a loop, is installed at 2 levels (1/3 and 2/3) of fence panels. SITES has developed the installation procedure, and optimized equipments, in order to save time during cable deployment. This site includes a main building in which the Brillouin instrumentation was installed and an internet secured link enables transmission to a Security Center. Several tests were conducted to define any kind of un-intrusive events able to trigger an alarm: a body

leaning on a panel, one or several ball strokes at the center of a panel, foot hits on a panel bottom, scraping a stick on one to five panels, resonance effect on the cable, a ladder on the fence followed by fast or slow climbing. A cutoff test of a fixing tie in the center of a panel was performed, proving both easy detection and localization. The alarm threshold was experimentally set, and the system conjointly runs with an IR imaging system to get redundancy on the intrusion detection. A 6-month trial has been performed to improve the filtering of thermal effects as well as dynamical perturbations (wind, snow, un-intrusive events like soccer ball shooting on the fence).



Figure 5. RTE electrical Substation (South-East of Paris, France) and sensing cable installation on fence

## 6. CONCLUSION

This project has linked several partners motivated by security, about the development and qualification of a monitoring system devoted to intrusion detection, based on Brillouin distributed sensing. A new optical fiber sensitive cable has been developed, and produced by an industrial process leading to a cost-effective solution, to measure strains induced by any event on the fence, and its innovative way to deployed patented. The complete instrumentation has been installed and tested on an RTE substation. A robust signal processing free from weather-based perturbations was developed. On field, the system is completed by video cameras for distinguishing real intrusion attempt from extra events when alarm occurs, and the machine-man-interface provides a simple representation of the cable deployed on the site, in real time. Many tests were conducted to improve both sensitivity and accurate identification of events that occur from time-to-time on this sensitive electrical substation.

## ACKNOWLEDGMENTS

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## REFERENCES

- [1] Taylor, H. F., and Lee, C. E., "Apparatus and method for fiber optic intrusion sensing." U.S. Patent 5 194 847, March 16, 1993.
- [2] Park, J., Lee, W. and Taylor, H. F., "A fiber optic intrusion sensor with the configuration of an optical time domain reflectometer using coherent interference of Rayleigh backscattering", Proc. SPIE, 3555, 49-56 (1998).
- [3] Juarez, J. C., Maier, E. W., Choi, K. N., and Taylor, H. F., "Distributed fiber-optic intrusion sensor system", IEEE J. Lightwave Technol , 23(6), 2081-2087 (2005).

- [4] Rao, Y., and Li, J., “Distributed intrusion detection based on combination of  $\phi$ -OTDR and P-OTDR”, Proc. The 19th Int. Conf. on Optical Fiber Sensors (OFS-19), Perth, Australia, 14-18 April 2008, Paper number: 7004-77.
- [5] Rao, Y.-J., Luo, J., Ran, Z.-L., Yue, J.-F., Luo, X.-D, Zhou, Z., “Long-distance fiber-optic  $\Phi$ -OTDR intrusion sensing system”, 20th Int. Conf. on Optical Fibre Sensors (OFS-20); Edinburgh, 5-9 Oct. 2009, Proc. of SPIE Vol. 7503 (2008).
- [6] Rougeault, S., Dewynter, V., Giuseffi, M., Pinabiau, M., Ferdinand, P., Patent “Système de détection d'intrusion et procédé de montage d'un tel système”, Priority date : 1st Sept. 2010. Patent n° PCT/FR2011/051932 18 Aug. 2011.